Chapter 4
A Tri-Partite Framework of Forest Dynamics: Hierarchy, Panarchy, and Heterarchy in the Study of Secondary Growth

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4.1 Introduction

As a complement to the enormous literature on deforestation, there is now an emerging body of work on the interrelated topics of secondary vegetation (herbaceous or woody vegetation on previously cleared land), reforestation (growth of woody vegetation on previously cleared land), secondary forests (woody vegetation on previously cleared land, still distinguishable from mature forest), and forest recovery (woody secondary vegetation that increasingly approximates historical and contemporary mature forest in the same region), which we summarize with the term secondary growth (the emergence of vegetation on previously cleared land, whether via plantations or natural plant succession). There is growing documentation that whereas forests continue to fall, especially in tropical regions, secondary growth is expanding in temperate regions, and furthermore even in areas with deforestation, there is often considerable land under secondary growth (other chapters, this volume, especially Grainger).

Consequently, there is an expanding literature on the theoretical explanations for forest decline as well as secondary growth. As with the case of deforestation, most initial efforts to understand secondary growth drew on established theoretical frameworks originally developed for another topic, usually some long-studied focus within a discipline. The result in both cases has been a cacophony of explanations, some mutually incommensurate, most framed in distinct language due to the diverse assumptions being made. This state of affairs has resulted in confusion for audiences in other disciplines and has driven efforts to re-examine the assumptions and interrogate the blind spots of established theoretical frameworks. Such efforts constitute a means of forging integrative theoretical approaches that are more open to multiple explanations and more adaptable to specific contexts.

This chapter suggests an integrative approach for theoretical explanations for land use and land cover change (LULCC), featuring the case of secondary growth. The core of this chapter focuses on a tri-partite framework that draws on hierarchy theory from landscape ecology, the notions of "adaptive cycles" and "panarchy" from complex systems theorists, and the concept of "heterarchy," previously applied in archaeology and business management (Perz 2007, 2008). We deploy these components as heuristics by borrowing them from other purposes and applying them to understanding the causation behind secondary growth. Together, a hierarchical framework with panarchic dynamics that results in a heterarchical structure of causation constitutes a "tripartite framework of forest dynamics" (TFFD). These heuristics can be criticized for being too abstract (cf. Walker 2007). We therefore employ examples involving secondary growth in the Brazilian Amazon to illustrate the TFFD, and conclude with a discussion of methodological applications.

We suggest that a TFFD provides a theoretical framework in which we can situate ostensibly competing explanations for secondary growth, and move beyond limitations in theoretical approaches such as grand theorizing, reductionism, and context-specificity (Perz 2007, 2008). We offer the TFFD as a means organizing explanations for secondary growth, rather than as a replacement. One of our goals is to avoid red herring debates about theoretical primacy among explanations, which results from

reductionism in the presence of competing explanations. We also suggest the TFFD as a means of avoiding the universalist pretensions of isomorphic grand theorizing as well as the haphazardness of context-specificity. By offering a framework in which various explanations can be arranged and evaluated, we can see to what extent a given explanation applies across cases, while recognizing that the configuration of explanations itself may vary from place to place. This allows for systematic comparisons in a common framework while acknowledging uniqueness.

4.2 A Tri-Partite Framework of Forest Dynamics

By now there is no shortage of theoretical perspectives seeking to provide explanations for LULCC (Gutman et al. 2004; Lambin and Geist 2006; Moran and Ostrom 2005). A major challenge is how to evaluate multiple theoretical perspectives across many cases, in order to select some explanations and abandon others (Lambin and Geist 2006). There is increasing attention going to the need to find some means of integrating theoretical arguments in a broader framework that can also specify factors that make certain theoretical perspectives particularly relevant in specific contexts while considering a standard set of explanations across many cases (Lambin and Geist 2006).

There are several requirements of integrative frameworks which pose serious challenges to theoretical integration. First, an integrated framework must account for the different levels of scale on which distinct causal processes operate. In terms of theory, this has as much to do with the operation of actual processes as with the resolution and extent of observation. In terms of socioeconomic explanations, it is crucial to distinguish among various social actors, from individuals to communities to governments to international coalitions, for they have different arenas of influence, diverse interests and operations, and varying LULCC impacts.

Second, an integrated framework must have some means for specifying the direction of causal relationships, of sorting out direct and indirect causation, and thereby specifying chains of causal processes and conditioning factors. Reductionist approaches and assumptions of isomorphic causation and universal applicability help little in explaining forest dynamics across different contexts. An integrative framework therefore must provide some structure in which a given set of explanations can be situated for consideration, and retained if they gain empirical support.

Third, an integrative framework must account for complex dynamics of forest cover change. Forest dynamics themselves are variable, and this requires some explanation. Forest change may be fast or slow, localized or widespread, and thus exhibits complex spatio-temporal patterns. In terms of theoretical explanations, there is a need to evaluate what accounts for rapid or slow forest change. Further, it is important to pay attention to feedback effects, for land use decisions yield ecological as well as socioeconomic outcomes that can change decision contexts.

And fourth, an integrated framework must incorporate the possibility that key causal factors themselves may change over time. Switching of causation has primarily

been addressed via empirical observation, though it is seen by some as consistent with sufficiently abstract theories as well. Predicting changes in causation remains a dubious proposition, but any framework that seeks to account for forest change still needs to be able to accommodate changes in causal processes to explain forest dynamics.

Here we suggest a TFFD that addresses these requirements (Perz 2007, 2008). We discuss hierarchy theory as a means of addressing the scale and causal sequence requirements; we draw from the notions of adaptive cycles and panarchy to account for slow-fast dynamics in causal factors and non-linearities in forest change; and we deploy the concept of heterarchy to recognize that causal factors and causal structures may change over time. If the TFFD we suggest is not an elegant formulation, neither are the dynamics nor the causation involved in forest change. We are well aware of criticisms of the three components of the TFFD, and address criticisms in our remaining text. Specifically, we respond to criticisms of the initial components of the TFFD by incorporating the later components, and we deal with broader criticisms of our approach in the conclusion.

4.2.1 Hierarchy Theory

Hierarchy theory emerged out of landscape ecology as a means of organizing numerous biological processes in terms of the spatio-temporal scale ("level") on which they operate so as to better organize and understand their relationships, from the cellular to the ecosystem level (O'Neill, et al. 1986; Allen and Starr 1988; Ahn and Allen 1996). This was based on the observation that many biological processes that operate on a small scale tend to be rapid and frequent, whereas those operating on larger scales tend to be slow and infrequent. Further, the operation of small-scale biological processes is periodically affected by the larger-scale processes, following the rhythm of the larger-scale processes. The key insight of a hierarchical perspective is that entities operating on one scale, especially larger scales, condition the operation of entities on other scales, especially smaller scales. As a result, hierarchy theory provides a structural approach to understanding ecosystems as nested sets of entities, with cells operating within organs, organs within organisms, organisms within ecosystems, and so forth.

A hierarchical perspective can be viewed as a heuristic (cf. Abbott 2004) and applied not only to understand the structure of ecosystems, but also causal pathways. If we apply the hierarchy heuristic to the causation behind forest change, we can deploy hierarchy theory as a framework that can elucidate the organization of processes affecting secondary growth. That is, large-scale determinants of LULCC condition the effects of smaller-scale determinants, which then directly affect forest change as via secondary growth.

A hierarchical approach offers several advantages as an integrative theoretical approach. First, a hierarchical framework explicitly recognizes that there are multiple causal and conditioning processes operating on different spatial scales.

Whereas scale is often featured in theoretical discussions of LULCC (Lambin and Geist 2006), discipline-based theoretical perspectives often focus on one scale or another. Acknowledgment of scale-specificity in causation allows us to situate a variety of explanatory factors, regardless of disciplinary origin, in a hierarchical framework by locating explanations on scales they feature.

Second, hierarchical frameworks organize causal processes in a specific way in order to sort out proximate, intermediate, and distant mechanisms. Causal proximity is also emphasized in the LULCC literature (Geist and Lambin 2002; Lambin and Geist 2006). Hierarchical frameworks view the locus of LULCC as the result of specific land use decisions, making micro-scale factors tied to land users proximate causes, with larger scale factors that influence land users intermediate causes, and macro-scale mechanisms distant causes. By organizing micro-, meso-, and macro-scale processes in terms of causal proximity to an outcome, we can forestall theoretical debates about causal primacy, and avoid captivity to a theoretical framework confined to one discipline or another. We note that hierarchical frameworks need not be limited to three scales, and can accommodate more if necessary.

Third, given the emphasis on spatial scale as a means of organizing causal processes, hierarchical frameworks can explain multi-scale spatial variations in secondary growth. Hierarchical frameworks thus link the scale of variation in secondary growth to the causal factors operating on that scale. Micro-scale variations in land cover are most likely due to proximate variations among land users; meso-scale variations are due to differences in intermediate-scale factors; and macro-scale variations are due to distant, large-scale causes.

The complex causation behind LULCC, and the many socioeconomic explanations offered to account for secondary growth, has made hierarchical frameworks attractive to social scientists (Gibson et al. 2000; Wood and Porro 2002; Perz 2002; Warren 2005). Social science explanations for secondary growth focus on identification of relevant social actors ("agents") who operate on specific spatial scales ("arenas of influence"). Examples of social actors and their arenas of influence include farm families with rural properties or logging firms with timber concessions. Such social actors constitute distinct "decision units" with specific land areas over which their decisions directly influence forest change.

Focusing on proximate social actors allows us to identify specific decisions they may take that directly affect the areal extent and age composition of secondary growth. In the Brazilian Amazon, there are several such land use decisions: (1) let land lie in fallow, (2) abandon a plot within a property, (3) abandon an entire property, (4) allow secondary growth in pastures, (5) modify forest cover (via selective timber extraction) , (6) plant valuable trees, or (7) engage in new or expanded land use (Perz and Walker 2002; see also Crews-Meyer, this volume). Whereas the first five decisions will result in an increase in secondary growth via plant succession, the sixth involves reforestation via more artificial means, and the seventh will either not affect secondary growth (if new land use is on land not previously under secondary vegetation) or will reduce it (if new land use is on land formerly under secondary vegetation). These decisions are illustrated in Fig. 4.1.

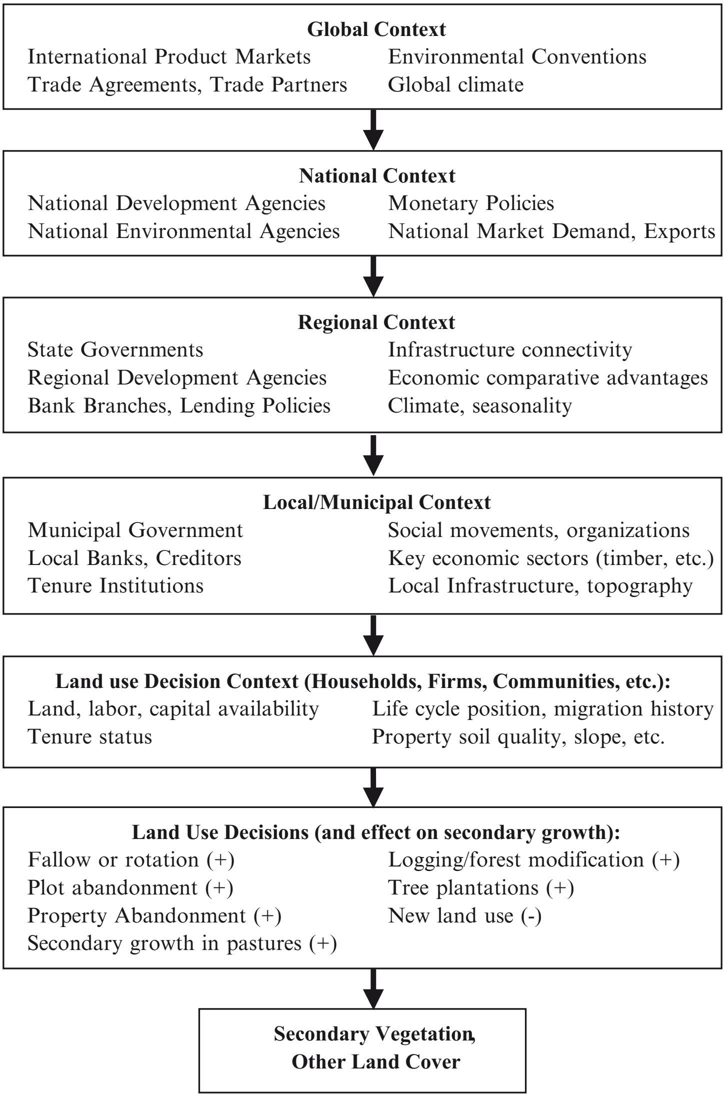

Fig. 4.1 A hierarchical framework of causal agents influencing secondary vegetation and other land covers (only top-down causation shown; bottom-up feedbacks also possible)

That said, the broader context in which decisions are made is crucially important. It is therefore necessary to account for the “decision context” of proximate social actors. The most immediate decision context for social actors is defined by their own characteristics. In economic terms, the “decision latitude” of social actors reflects their land, labor and various capital assets. Such assets help determine their goals with land use decisions as a means of achieving those goals, which then defines the logic of their land use decisions and the consequent land use

patterns. Family land use is greatly influenced by their available labor; logging firms make decisions based on their capitalization. See the land use decision context box in Fig. 4.1.

In turn, the land use decisions of micro-level social actors are partly dependent on the larger scale context in which they operate. At this point the contributions of a hierarchical perspective become evident, for we can view social actors who make decisions that directly affect land use as micro-level agents operating in a broader socioeconomic and biophysical context that affects their decisions. Households and logging firms operating in a given locality face contextual circumstances defined by local politics, infrastructure quality, etc. that reflects the operation of municipal governments and other agents who have larger arenas of influence (see Fig. 4.1).

For purposes of exposition, we follow Vayda (1985) who proposed "progressive contextualization" as a means of identifying causes behind an outcome. In progressive contextualization, one begins by observing the outcome of interest – in our case, secondary growth – and then proceeds to identify proximate causes – in our case, land use decisions. One then "progressively contextualizes" those decisions by looking to their immediate context, such as household or firm characteristics, and then situating those decision contexts in ever larger, more distant contexts, such as at the community or municipality levels to identify key characteristics of those entities that can help account for the behavior of the proximate decision units. Through progressive contextualization, we can identify factors that account for land use decisions by looking to the structural context of decisions in order to identify facilitators and constraints. This in turn allows identification of cross-scale causation that affects land use decisions.

Progressive contextualization can be used heuristically to populate a causal hierarchy by theoretically identifying causal factors operating on ever larger scales. A key contribution of progressive contextualization is that via induction it considers progressively larger-scale contexts at which to identify causal factors which then become situated on distinct scales in a hierarchy of causation. This inductive process allows us to organize a set of causes, from the micro-level to various meso- and macro-levels. Decisions to allow secondary growth by households, firms, and other micro-level social actors can be situated in a local context at the municipal level, a regional context of the Amazon basin itself with specific policy programs and comparative advantages, the national context of Brazil with a particular policy environment, and the global context with commodities markets and trade agreements (Fig. 4.1).

Per the intent of progressive contextualization, there is no requirement that the causal factors be identified on a predetermined spatial scale, and it is not necessary that specific explanations, tied to certain disciplines or theoretical perspectives, be found as crucially important. In this sense, a causal hierarchy does not privilege one sort of explanation over another, but rather provides the structure in which various explanations can be situated and related to each other.

While progressive contextualization works from the "bottom up" so to speak, that is from the micro-level to the meso- and macro-levels, it does so to identify causation running "top-down," with the consequence that the resulting hierarchy of

causation highlights mechanisms operating on the larger scales that influence what happens on smaller scales (Fig. 4.1). In a hierarchical perspective, the reforestation in the Amazon is the result of a variety of processes operating on multiple scales (Perz and Skole 2003). Global opportunities and constraints condition the national context in Brazil, which in turn influences the regional context of the Amazon, local municipalities, and eventually proximate social actors making land use decisions. Global demand for tropical timber can influence national policies for the timber sector, regulations on timber extraction in the Amazon, municipal politics concerning the logging sector, and the behavior of logging firms and colonists with timber on their land, resulting in forest modification that fosters the subsequent emergence of secondary growth in canopy gaps opened by logging activity (Fig. 4.1).

The emphasis on top-down processes has generated criticism of hierarchy theory for its perceived structural determinism. It is important to emphasize that distant, large-scale processes are indirect causes, whose effects can be modified by intermediate and proximate determinants that serve as intervening variables. While it may be the case that high prices on tropical timber in global markets would drive more timber extraction and secondary growth in modified forests, the effect of such demand will vary from place to place. Some countries have more tropical timber than others; some regions as well. Spatial variation can emerge at each level in a hierarchy of causation, such that a global timber demand effect would manifest itself more in some countries, regions, localities, and properties than others, due to biophysical variations in the spatial distribution of timber stocks and responses by social actors with timber and the capital to extract it. As causation cascades down a hierarchy, to the extent that factors operating on smaller scales are important, they will differentiate the effects of the higher-scale process, yielding spatial variation in land use decisions and secondary growth. To the extent that factors on multiple scales exert moderating effects, they create complex patterns of variation on those scales, such that secondary growth exhibits national, regional, local, and property-level variation.

We have emphasized socioeconomic explanations, particularly economic factors, but we also recognize that other social factors can also be relevant, as are biophysical factors. This complicates the hierarchy of causation. It is easy enough to progressively situate local, regional, national and global markets via distribution chains, or to do the same for policies across administrative levels. But if we attempt to consider both socioeconomic and biophysical factors at the same time, we begin to encounter scale mismatches. If a specific causal mechanism runs from regional policies to municipal markets, then the picture is reasonably straightforward, for municipalities can be situated neatly within administrative regions, a presumption of a hierarchical framework. But if there are multiple causes tied to spatial units that don't neatly fit one within another, such as cultural areas or watersheds, then the hierarchy of causation less clear because causation does not pass neatly among nested levels of scale.

Another issue with hierarchical frameworks is the tendency to emphasize cross-scale ("vertical") causation at the expense of attention to within-scale ("horizontal") causation. While global conditions may well influence national, regional, local, and

micro-level processes, it is just as likely that multiple local or micro-level factors may be operating at the same time and influencing each other. Elections in many frontier areas of the Amazon are often determined on the basis of favors to specific constituencies, especially favors that influence their ability to market produce, as via road maintenance (Perz et al. 2007). Consequently, a local political outcome may result from local road maintenance during the campaign that facilitates new land use and the reduction of secondary growth. Further, land use decisions are made simultaneously with respect to different land covers, such that household decisions about timber, crops, pasture, and off-farm activities may all affect the extent of secondary growth on a property (Perz et al. 2006).

Another issue concerning cross-scale causation is the assumption that factors at a given scale only directly affect those on the scale immediately below, and necessarily have only indirect effects on several scales below. This raises the issue of whether mechanisms at intervening scales always serve to moderate the effects of a large-scale process. This is not necessarily the case. Movement of the timber frontier, driven by global demand for tropical timber, yields local shifts in the emergence of secondary growth as timber firms move, making decisions directly on the basis of ongoing global demand.

Related to questions of top-down causation is the issue of neglecting bottom-up processes. If individual landowners form producer associations to improve market access via economies of scale for their production, they may be prompted to expand their fields at the expense of secondary vegetation, reducing it at the local or perhaps even the regional level. Such mechanisms constitute bottom-up feedback effects that originate with individual property owners but result in larger-scale effects on secondary growth.

These examples however reveal another important critique of hierarchical frameworks, namely that they emphasize causal structures and spatial variations at a given time but handle dynamics awkwardly. There is a tendency to fall back on assumptions about dynamics borrowed from landscape ecology, that is, small-scale processes operate faster, and thus can change faster, than larger-scale processes. This assumption is questionable since large-scale social actors can change behavior quickly in some instances, such as national policy changes after landslide elections. The dynamics of secondary growth require more attention than hierarchy theory by itself can offer. To address this last critique, we turn to the second component of our TFFD.

4.2.2 Adaptive Cycles and Panarchy

A key issue in the study of forest dynamics concerns the temporal scales on which secondary growth can vary over time. Whereas forest transition theory rightly emphasizes that there are long-run trends in primary and secondary forest cover (Walker 1993; Mather and Needle 1998), remote sensing analyses have also called attention to important short-term changes in the Amazon (Lucas et al. 1993; Steininger 1996), as well as medium-term changes over a decade or more (Skole et al. 2004).

It becomes evident that theory about secondary growth, and other types of LULCC, needs to account for short- as well as medium- and long-term dynamics. In this section, we draw on notions of "adaptive cycles" and "panarchy" to account for the dynamics of secondary growth on multiple temporal scales, as well as changes in causal processes behind those dynamics.

The "adaptive cycle" was theorized to account for slow and fast functioning of ecosystems and their components (Gunderson et al. 1995; Gunderson and Holling 2002). An adaptive cycle has four stages. The first is the "r" stage, also called "growth" or "accumulation," which occurs when the variables that define an ecosystem are tightly linked and there is considerable accumulation of biomass and nutrients. As the cycle continues, the ecosystem moves to the "K" stage, also known as "conservation," which involves a slow-down in growth as the system exhausts available nutrients. This slow phase eventually gives way to the "Ω" stage, also called "creative destruction," when connectivity among ecosystem properties drops and the accumulated natural capital is liquidated, freeing it up for conversion into something else. This involves much faster dynamics than r or K. The creative destruction phase soon is followed by the "α" stage, or "reorganization," when available nutrients and biomass again accumulate in a context of an incipient rise in linkages among system variables. Reorganization involves rapid dynamics which eventually slow in a new r stage as available nutrients decline and biomass again accumulates while linkages among system variables again become established.

A classic illustration of the adaptive cycle from ecology is secondary vegetation succession itself on a forest plot that has been cleared (Berkes and Folke 2002). Pioneer species of plants colonize the plot and grow for several years (in the r stage). Later, slower-growing species come to dominate and the vegetation structure changes more slowly (in the K stage). Eventually, a person cuts the plot down or a fire burns the plot in a short period of time (per the Ω stage). After this, the remaining seed bank yields new sprouts and vegetation (in the α stage), which gives way to a new r stage.

As with hierarchy theory, we view the adaptive cycle as a heuristic (cf. Abbott 2004) and apply certain aspects to the causal processes behind secondary growth. Rather than focus on the adaptive cycle of ecosystems and their components, we focus on the adaptive cycles of the components in a causal hierarchy. Each component in a causal hierarchy can exhibit slow or fast operations, which we account for with the heuristic of the adaptive cycle. This provides a means of accounting for switches between slow and fast operations among the social actors and other entities in a causal hierarchy.

The content of the operations of specific agents then becomes important to consider. With respect to proximate causes of secondary growth, those operations involve land use decisions. Proximate agents define land management in terms of production goals, which resemble the α stage, when land use decisions are taken and new land covers appear. Agents then pursue those goals, per the r stage, where a land use system becomes established and may expand. This continues until the system encounters a constraint that hinders further implementation (K stage), when operations slow and change ceases. Further, when a crisis and/or opportunity arises, whether induced externally or via an internally planned change of goals (as in Ω), previous land use may be

discontinued or rapidly modified. The agent then envisions new production goals (α again), when new land use decisions are taken. For landholders in the Amazon, this adaptive cycle may involve the seasonal routine of land use decisions, such as the clearing of vegetation, planting, and harvesting of annual crops, or the breeding, calving and culling of cattle, both of which occur in synchrony with an annual cycle.

However, a given causal agent may have more than one adaptive cycle. This reflects the fact that a given social actor does not do just one thing, and may have various operations, each with its own temporal rhythm. A given causal agent can thus exhibit a set of adaptive cycles, some with longer periods than others (Almeyda 2004; Gallopín 2002). While farm households may cultivate following an annual cycle, they also engage in implementing their farming system over a period of many years, following the demographic life cycle of the family over a generation (Perz and Walker 2002; Perz et al. 2006).

To elaborate an Amazon example applied to secondary growth, consider a young colonist family which arrives on the frontier and clears forest to establish a land claim and grow annual crops for food security. During the course of the annual cycle of planting and harvesting, fast changes occur when land use decisions are implemented, particularly preparation of plots (by clearing out mature or secondary vegetation) and during harvest; slower changes occur as crops grow and after harvest when secondary vegetation emerges. In addition, over several years, land productivity declines and weeds invade, which requires clearing of other plots of land and results in advanced secondary growth on the initial cultivated plot. This longer cycle depends more on the length of time until soil fertility declines and on the ability of the household to clear more land, which tends to occur periodically every several years. The longer adaptive cycle still involves land use decisions by the household, but punctuates the annual decision-making by expanding the total area cleared of mature forest as well as the area with secondary growth. The fast dynamics on this cycle occur in those years when it is necessary to abandon a given plot and clear a new one; the slow dynamics proceed in between the abandonment/clearing years. The combined result is seasonal fast–slow changes in the area under secondary growth, punctuated by periodic increases (once every several years) in secondary growth due to fallowing or plot abandonment. In this sense, a given causal agent with multiple adaptive cycles may exhibit slow–fast behavioral changes that result in non-linear changes in secondary growth over time.

All that said, Gunderson and Holling (2002) emphasize that shifts among slow and fast dynamics of a given causal agent also reflect responses to changing contextual circumstances. This is a crucial point: slow–fast changes in one agent's operations can result in additional changes in the operations of other agents entrained in the causal hierarchy. Just as hierarchical frameworks theorize top-down causal cascades, adaptive cycles of agents in causal hierarchies prompt one to theorize that slow–fast changes in large-scale agents can entrain slow–fast changes in lower-scale agents. In this way, we can link hierarchies of causation to slow–fast dynamics in the adaptive cycle of a given causal agent. Shifts among slow and fast operations of various agents in a causal hierarchy thus provide an additional theoretical basis that accounts for slow and fast dynamics in secondary growth.

By explicitly incorporating fast–slow dynamics in causal agents, adaptive cycles set a causal hierarchy in motion, which leads us to our rendition of the concept of a panarchy (Gunderson and Holling 2002; Holling 2004). For our purposes, a panarchy amounts to a causal hierarchy with agents that exhibit slow and fast operations over time.

It is useful here to reflect back on the assumption of hierarchy theory that agents operating on larger scales tend to operate more slowly, with small-scale agents operating more rapidly. This is not to foreclose on the possibility of rapid change at a large scale. The adaptive cycle makes explicit that all agents, regardless of the level they occupy in a hierarchy, have slow and fast dynamics, so while global agents may operate slowly most of the time, abrupt changes can also occur periodically. That said, large-scale agents tend to be very complex, involving large aggregations such as populations or complicated structures such as bureaucracies, which tend to exhibit considerable inertia and are difficult to rapidly redirect. The global climate system does not change as fast as local weather; by the same token, it generally takes more time for the UN general assembly to gather for important decisions than a local government commission. While all agents in a causal hierarchy can exhibit fast operations, on average large-scale causal agents go through their adaptive cycles more slowly, with less frequent periods in r and K than small-scale agents.

Considered as a whole, different agents in a causal hierarchy will be at various stages of their respective adaptive cycles. This results from the differing lengths of adaptive cycles of various agents due to their different operations and logics. Seasonality, household life cycles, market price fluctuations, election cycles, and other factors that can influence land use decisions do not have the same temporal rhythms. But the mere recognition that different agents have adaptive cycles of differing periods bears important implications for the hierarchy of causation and the resulting dynamics in secondary growth.

One key implication is that at a given moment, agents in a causal hierarchy are not necessarily at the same stage in their adaptive cycle. That is, there is not necessarily synchrony among agents. Asynchrony leads to a crucial point: the adaptive cycle stage of a large-scale agent in the causal hierarchy can affect the stage of adaptive cycles of other agents at smaller scales in the panarchy (Holling et al. 2002). The asynchrony of adaptive cycles in a causal hierarchy implies that punctuations wrought by various large-scale agents entering fast stages will occur periodically, at variable intervals. Improved roads, growth in urban markets, new lines of credit, rising demand for timber, declining prices for key cash crops, and other changes in the contexts of land use decisions can occur periodically, and greatly alter the goals and logic of proximate decision units (Perz 2002).

This leads to specific arguments about the effects of slow–fast switches in operations of one agent on the pace of operations of other agents. In brief, if one agent in a causal hierarchy enters the Ω stage and exhibits rapid operations that change, this slow–fast shift may require other agents, causally entrained, to similarly enter a stage of fast operations, as a means of responding and adapting (see Fig. 4.2, panel a). The dynamics that result among lower-scale agents amount

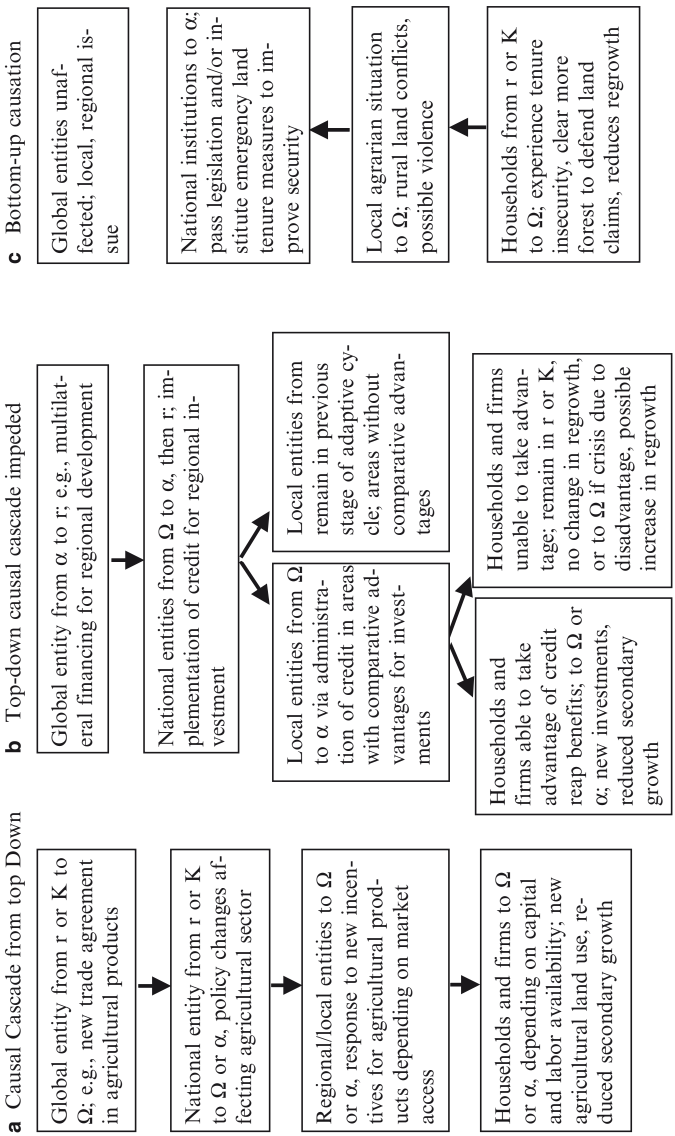

Fig. 4.2 Adaptive cycles and panarchic dynamics in hierarchical causation behind secondary growth: (**a**)–(**c**)

to "punctuated adaptation" to changes cascading down the causal hierarchy. Lower-scale agents may also enter the Ω stage in the case of a real crisis for which lower-scale agents are unprepared or to which they are incapable of responding, or perhaps the α stage if the rapid large-scale changes present opportunities for which lower-scale agents are prepared, or to which they are capable of responding (Fig. 4.2, panel a).

Cascading changes from global, national, regional and local agents ultimately impact proximate agents, who at a given time will be in diverse stages in their adaptive cycles (cf. Westley 2002). A change in the operation of agents atop a causal hierarchy catalyzes alterations in the operation of agents below, such that their stage in key adaptive cycles is changed to α or Ω, regardless of what stage those agents were in before. Sudden shifts in global product prices and bank lending policies may alter the availability of capital to rural producers in the Amazon, affecting their decision logics and prospects for continuing or expanding production, which then alters prospects for fallowing and other decisions affecting secondary growth. Such shifts can "punctuate" household adaptive cycles, prompting households to "jump" from the r stage immediately into the Ω stage, skipping a prospective K stage (Fig. 4.2, panel a). This implies that agents do not necessarily pass obediently through all stages of their adaptive cycles.

That said, lest we be too carried away with structural determinism, it is important to also recognize that the responses of smaller-scale agents to cascading punctuations in the causal hierarchy may be differentiated. That is, cascading slow–fast shifts may affect some localities more than others, and may impact some landholders more than others (see Fig. 4.2, panel b). If crop price drops are more important for producers in some places than others, only producers in the affected municipalities will experience jumps in their adaptive cycles. Similarly, to the extent that there are inequalities among producers, such that some have more diversified livelihood portfolios, more bank credit, or more capital, the responses of producers in the same locality can also vary (Fig. 4.2, panel b).

Against structural determinism, we can push back farther via panarchy. While the foregoing examples emphasized "top-down" cascades of causation involving shifts in stages of adaptive cycles, there can also be "bottom-up" cascades (Fig. 4.2, panel c). To this point we have made much of asynchronies in adaptive cycles among agents in causal hierarchies. Now we want to emphasize the importance of synchronies in adaptive cycles among many causal agents. Periodic convergences in the stages of adaptive cycles of micro-level agents can generate bottom-up feedbacks and result in changes in the operations of larger-scale agents. Simultaneous tenure insecurity among many landholders can result in rural violence that in the Amazon historically begets state action via land titling (Schmink and Wood 1992). Tenure security may in turn motivate new land use that reduces secondary growth. In this example, convergence of many micro-level actors (land claimants) at Ω (via rural violence in the struggle over land claims) led to higher-level agents (the state) to shift into α (legislation permitting emergency land titling operations). Thus, a bottom-up process involving fast dynamics cascaded up the causal hierarchy, generating faster dynamics at higher levels, which in turn resulted in later shifts in secondary growth (Fig. 4.2, panel c).

Beyond punctuated adaptive cycles due to cross-level interactions, there are more fundamental changes that can occur in a causal hierarchy. One such change involves alterations in the composition of the agents themselves. Turnover in the agents relevant to land use in a given area, as via migration, can alter a causal hierarchy and change land use decision-making and secondary growth. Rapid in-migration during the 1970s and 1980s to the Amazon constituted new populations with resource management practices that differed from indigenous and other traditional groups, which led to non-traditional land use systems that involved extensive land cover conversion (Schmink and Wood 1992). Changes in the profile and composition of relevant land users in turn altered land cover dynamics, such as via the expansion of pasture, followed by widespread land degradation (Serrão and Homma 1993) and emergent secondary growth (Perz and Skole 2003). Similarly, changes in the institutional context can alter land use decisions. In Brazil, the creation of extractive reserves, agro-extractive settlements, and other innovative land tenure categories have either legitimated traditional practices or imposed new rules on pre-existing land tenure types (for other examples, see chapters by Grainger and Crews-Meyer, this volume).

Panarchic dynamics can bring about yet more fundamental changes, up to and including alterations in the locus of key causal processes or even changes in the causal structure itself. Brazil's new constitution in 1988 led to fiscal decentralization, which had the effect of relocating responsibility for many state services from federal agencies to municipal governments (Souza 1997). The result was that municipalities gained more control over state functions tied to local development. That is, institutions tied to distribution of public resources were shifted from a high, distant level in the causal hierarchy to a lower, more proximate level. This shift made it easier for local landholders to demand state services and infrastructure as political favors to facilitate expanded production systems (Toni and Kaimowitz 2003). Decentralization of state functions also spurred the creation of new municipalities in the Brazilian Amazon during the 1990s ("municipalization") as local players sought to carve out new spaces for local control over state resources. Along with decentralization, municipalization made local circumstances more important for land use decisions than before.

In sum, adaptive cycles and panarchy provide several theoretical explanations as to why secondary growth exhibits short-, medium- and long-term dynamics: (1) slow–fast dynamics in adaptive cycles, (2) multiple adaptive cycles with different temporal scales in a given causal agent, (3) varying temporal periods among adaptive cycles of different causal agents, (4) asynchrony in adaptive cycles among different causal agents, (5) cascading causation that involves shifts and jumps ("punctuations") in the stages of adaptive cycles among many causal agents, whether via top-down or bottom-up cascades, (6) differentiated responses of smaller-scale causal agents due to their heterogeneity in preparedness or capacity to deal with punctuations, (7) changes in the composition of causal agents, and (8) changes in the causal structure, via alterations in the proximity of certain causes. Rapid dynamics in secondary growth, especially on smaller spatial scales, occur due to shifts from slow to fast operations by micro-level land users. Rapid dynamics also result when large-scale

agents enter fast stages and entrain cascades of rapid operations among other causal agents. Conversely, slow dynamics can result from a pre-eminence of agents at “slow” stages in their adaptive cycles, and when rapid large-scale processes are inhibited by intervening agents in the causal hierarchy.

4.2.3 Heterarchy

The concluding portion of the foregoing section raised the issue of structural changes in the causal hierarchy due to panarchic dynamics. If shifts in the causal structure are frequent, or if causation frequently “skips” over levels in a hierarchy, then the assumption of strictly hierarchical causation becomes less accurate. In this section we therefore present the notion of “heterarchy” as an emendation to hierarchical assumptions. We view heterarchical causal structures as the result of panarchic dynamics applied to hierarchical frameworks.

Heterarchy emerged out of general systems thought and chaos theory as a response to reductionism and post-modernism in the analysis of complex dynamic systems (Beekman and Baden 2005). Like hierarchy theory, the notion of heterarchy has been appropriated and adapted by other disciplines. In the social sciences, one application has been in organizational research on the changing relations between multi-national corporations and their subsidiaries (Birkinshaw and Morrison 1995); another has been on globalization and the reorganization of national economies (Amin 2004), particularly in post-socialist economies of the old Soviet bloc (Stark 2001). In each, presumptions of hierarchical, top-down organization have met with empirical difficulties as firms exhibit new forms of flexibility and organization, as economies reorganize horizontally as well as vertically, and as the structures of socialist economic organization give way and become more fluid. The primary application of heterarchy, however, has been in archaeological research on the political and economic organization of pre-historic societies (Crumley 1994; Ehrenreich, et al. 1995). Once understood to have been controlled top-down in hierarchical fashion by elites, these societies are increasingly viewed as having multiple forms of organization, with important lateral and bottom-up organizational mechanisms, and considerable plasticity in their structures when viewed over time (e.g., Rautman 1998; O’Reilly 2003; Scarborough et al. 2003).

We deploy the concept of heterarchy as a heuristic (cf. Abbott 2004) and apply it to causal structures behind LULCC, specifically the case of secondary growth. For our purposes, heterarchy refers to a set of relationships among entities that includes both hierarchical as well as non-hierarchical relationships. Here it is important to highlight the differences between hierarchical relationships – which occur among ranked entities, are highly structured, and largely uni-directional (top-down) – and non-hierarchical relationships – which occur among unranked or variably ranked entities, are flexible, and are multi-directional (including horizontal and bottom-up). Whereas hierarchical frameworks assume that causation proceeds obediently from one level to the next level, heterarchic causation relaxes this

assumption (thus the term “unranked”). Further, whereas hierarchical frameworks don’t readily handle dynamics in causal structures, heterarchic frameworks embrace such shifts by highlighting reorganization in causal sequences (thus the term “flexible”). And whereas hierarchical frameworks emphasize top-down causal cascades from large- to small-scale agents, heterarchic frameworks also pay attention to horizontal causation and bottom-up cascades (thus the term “multi-directional”).

Thus far, our definition of heterarchy has featured relationships between pairs of causal agents, but heterarchy also refers to the overall causal structure that emerges when considering hierarchical and non-hierarchical relationships among many causal agents. When speaking of heterarchic causal structures, it is important to recognize that the concept of heterarchy encompasses the concept of hierarchy but is broader. Heterarchy recognizes hierarchical assumptions as one type of causal structure, but emphasizes the importance of non-hierarchical causation.

We therefore elaborate on our initial definition of heterarchy, to consider not only its relational dimension (between pairs of causal agents) but also its larger structural dimension (the emergent causal structure resulting from relationships among many causal agents). Heterarchy thus refers to the combination of hierarchical and non-hierarchical causal structures that result from panarchic dynamics (i.e., the importance of horizontal causation within a level of scale, shifts in key causal sequences, and top-down as well as bottom-up causation). In other words, there can be specific non-hierarchical relationships among agents in a causal structure, and their presence, even along with hierarchical relationships, constitutes a heterarchic causal structure. A causal heterarchy thus encompasses both hierarchical and non-hierarchical relationships.

Heterarchy provides a means of grappling with critiques of hierarchy theory. One corrective is the equal emphasis heterarchy places on cross-scale and within-scale relationships. Whereas hierarchy tends to privilege top-down processes, heterarchy also recognizes the importance of bottom-up and horizontal as well as vertical relationships. We provided examples of both in previous sections of this chapter for the case of secondary growth. For horizontal (within-scale) processes, we observed that household characteristics affect household land use decisions, so that households with more labor and capital tend to have larger production systems and less secondary growth. For bottom-up processes, we noted that individual decisions to participate in collective mobilization in order to organize producer cooperatives can improve market access, expanding the local land area under production and reducing the area under secondary growth.

However, heterarchy does not mean that all possible relationships, among all scales, running in every direction, are necessarily important. Like hierarchy theory, heterarchy constitutes a framework within which specific theoretical arguments, whatever their disciplinary source, can be situated, if justified. Heterarchy like hierarchy demands a priori theoretical justification or an empirical basis for including a given type of causal linkage, whether it be top-down, horizontal, or bottom-up.

Heterarchy also allows us to deal with the problem of scale mismatch. Hierarchical frameworks tend to incorporate simplifying assumptions about the relevant scales based on disciplinary proclivities (e.g., local, regional, national administrative

areas for social scientists), precisely because of complications due to mismatches in the relevant scales when considering causal factors from other disciplines (e.g., watersheds, soil types, vegetation formations, and agroclimatic zones for biophysical scientists). By relaxing the assumption of nested scales in causal hierarchies, heterarchy provides a means of more easily incorporating causation across scales that does not occur among small-scale agents nested within larger-scale agents. Thus a heterarchical causal structure can acknowledge the importance of different soil types, which generally do not follow the boundaries of municipal administrative areas, in order to account for the effects of both soil quality as well as municipal extension or road maintenance resources as they may both affect land productivity and market access, and in turn affect the viability of land use decisions and secondary growth. We can still diagram cross-scale causation and follow causal chains systematically, but without the constraining assumption of purely hierarchical causation.

Heterarchical causation with scale mismatches implies that we must confront multiple sets of scales, that is, socioeconomic and biophysical. Each set of scales can be viewed as a distinct dimension of a multi-dimensional causal structure. Imagine several causal hierarchies as in Fig. 4.1 placed next to each other, with different sets of scales for each, and causal arrows running from one hierarchy to another. That in turn implies that we must then marry those dimensions in order to capture cross-dimensional causation running from socioeconomic to biophysical factors and vice versa. Areas of erosive soils and the presence of seed banks in nearby forest stands at the local level can be particularly problematic for sustained land use, especially among households with limited labor and capital, resulting in soil degradation and secondary growth, particularly among capital/labor-poor households. All this complicates matters, but heterarchy also requires selectivity about which relationships across different dimensions of the causal structure are important; again, theoretical or empirical justifications are necessary.

Perhaps most importantly, heterarchy accommodates panarchic dynamics that modify causal structures. This is a major focus in empirical research informed by the notion of heterarchy, whether via changes in firm-subsidiary relations in multi-national corporations, state-firm relations in post-soviet societies, or institutional rearrangements and shifts in elite-populace relations in pre-historic societies. Heterarchies can thus be characterized via different types of changes in causal structures. Here we note three such structural changes and provide examples of each as applied to the causation behind secondary growth. First, the operations of causal agents change via reallocation to different locations in a causal structure, modifying the proximity of key causal factors. Earlier we provided the examples of decentralization and municipalization, both of which shifted responsibility for and control over state services from the national to the local level, with impacts for local land use via differentiating the level of, for example road maintenance services among municipalities. See Fig. 4.3, panel a.

Second, the causal importance or proximity of a given causal agent may change, even if its scale of operation does not. Here a prominent example concerns multilateral banks, who have in recent years undertaken financing of major infrastructure

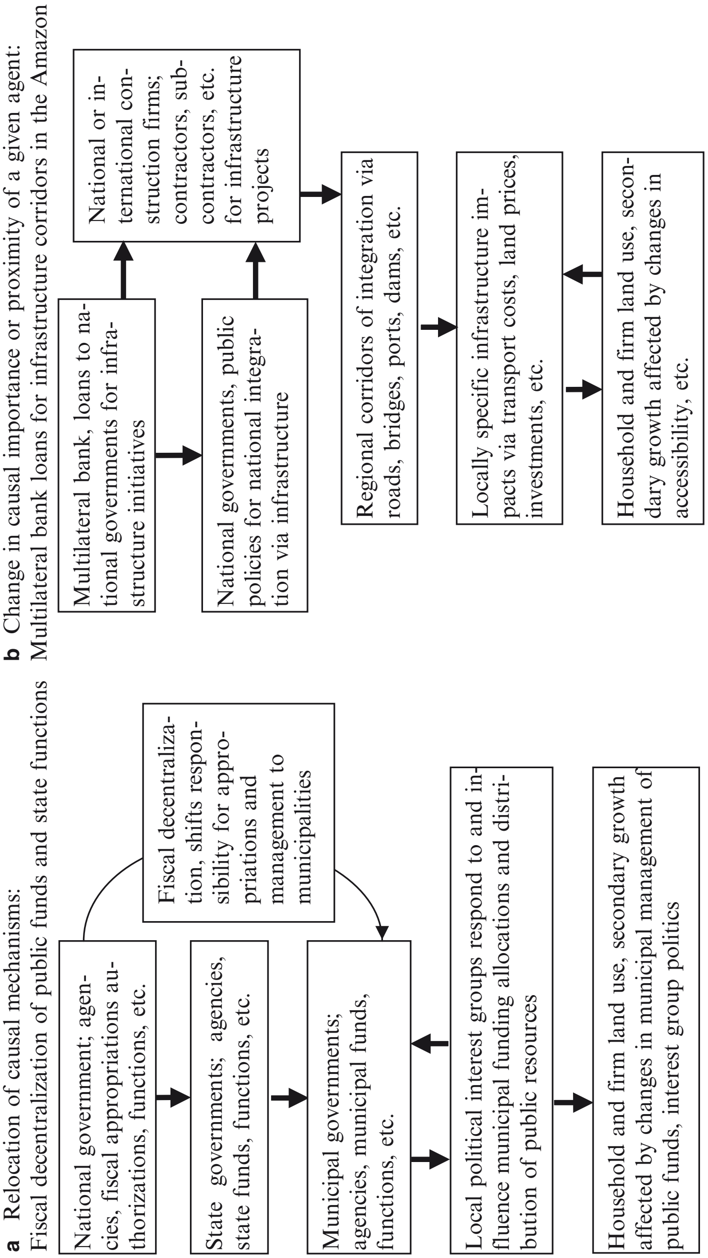

Fig. 4.3 Heterarchy via structural changes in causal pathways behind secondary growth: (**a**) and (**b**)

upgrades in many parts of South America, including in the Amazon (Mendoza, et al. 2007). Such upgrades have led to a new generation of direct investments of foreign loan funds that have reduced transportation costs and motivated intensified land use along paved road corridors, expanding land use and curtailing secondary growth. In the 1960s and 1970s, infrastructure investments resulted from state initiatives; in the 1980s, major projects were led by state-owned companies; now, the funders and the construction contractors are private entities from outside the Amazon, if not also Brazil. See Fig. 4.3, panel b. Third, the types of operations of a causal agent change, in turn altering the structural relationships to other causal agents. A salient example here concerns the shift toward mechanized agriculture, especially among landholdings previously featuring extensive cattle ranching. Whereas cattle ranching was initially a hedge against inflation and then became oriented to regional markets, soybeans are eminently an export product, which made global markets much more important for land use. The expansion of mechanized agriculture and the heavy capital and chemical inputs to sustain cultivation without multi-year fallow periods curtailed secondary growth in many parts of the Amazon.

In sum, in a heterarchic causal structure, the proximity, operations, structural relationships, and importance of causal agents change over time. The result in terms of the dynamics of the causal structure itself is that a heterarchy rearranges itself as the causal agents in the structure move around, change their operations and relationships, and may become more or less important over time. Viewed in empirical terms, changes in causal structures tend to occur at historically important moments such as elections, policy changes, changes in markets (whether due to trade agreements among countries, major new contracts with buyers, price support modifications, etc.), reorientations in land tenure arrangements, large-scale population movements, or efficacious grassroots movements. Similarly, climatic variability and prospect of climate change also present moments when causation behind land use decisions and secondary growth can change.

4.3 Conclusions

Even in places known primarily for deforestation, such as the Amazon, there is considerable secondary growth in previously cleared areas (Perz and Skole 2003), and secondary vegetation is expanding in area over time (Skole et al. 2004). However, cross-site comparisons of the causation behind secondary growth and other types of LULCC reveal complex and variable causation (Lambin and Geist 2006; Moran and Ostrom 2005; see also Rudel, this volume). This constitutes a challenge for theoretical frameworks, which should apply to many cases and also be adaptable to specific contexts (Perz 2007, 2008).

The tripartite framework of forest dynamics (TFFD) responds to the challenges involved in constituting an integrative theoretical approach for LULCC. The first part of the TFFD avoids the extremes of grand theoretic and context-specific avenues to explanation and still offers a systematic and yet flexible approach.

Hierarchy theory provides an encompassing structure in which many theoretical explanations can be situated. It recognizes the scale-specificity of explanations, and in the same stroke organizes them with respect to causal proximity to LULCC. The second part of the TFFD highlights dynamics in causation as a means of accounting for non-linearities in changes in LULCC. Adaptive cycles emphasize the capacity of causal agents to exhibit both slow and fast operations. Panarchy calls attention to different slow-fast periodicities among causal agents, asynchronies in the onset of fast dynamics among different causal agents, cascades of causation generating slow-fast shifts in operations, and other non-linear dynamics affecting causation. The third part of the TFFD stresses the combination of hierarchical and non-hierarchical causation, as well as structural changes in causation behind LULCC. The concept of heterarchy includes both hierarchical (top-down) as well as non-hierarchical (including bottom-up and horizontal) relationships, as well as causation across socioeconomic and biophysical causal structures that are unlikely to be hierarchically nested. The components of the TFFD thus provide heuristics that can be usefully appropriated from other purposes to address challenges facing theoretical integration to better understand LULCC.

There have been several critiques of the type of frameworks on which we draw to constitute the TFFD. One is the "philosopher's stone" critique, namely that the goal of creating an all-encompassing, "unified theory" of something as variable as LULCC is an unrealizable endeavor due to context-specificity. From this perspective, the causation behind LULCC is itself so variable that it cannot be approached systematically. This means that cross-case comparisons are impossible without doing analytical violence to the specifics of the cases being evaluated, because comparisons inevitably result in the loss of understanding of the causation involved in each case.

Conversely, there is the "excessive complexity" critique, which is that a TFFD that is open to any and all explanations becomes unwieldy for not focusing on specific substantive causes a priori, as via reductive or grand theoretic approaches. Here the argument is that it is far more analytically tractable to proceed deductively rather than inductively as via progressive contextualization, and to impose one or a few substantive arguments to be tested. This critique reflects the tensions between logico-deductive approaches to science that emphasize parsimony via the a priori selection of causes to focus analysis, and "holistic" approaches that feature multiple and contingent causation, and therefore require more open inquiry.

Both critiques miss the point of employing a TFFD in which various theoretical explanations may be situated. A key advantage of a hierarchical framework is to be able to incorporate different explanations in different cases, imposing a common assumption about the structure of causation rather than about the substance of the relevant causal processes themselves. The same applies to a heterarchic causal structure, which relaxes strictly hierarchical assumptions about causation. This universalist approach to the structure of causation differs from imposing a standardized expectation of a substantive cause to be important in all empirical cases. The TFFD proposed here thus avoids the proclivities of reductive explanations that propose to fit all cases by ignoring contextual differences (as in e.g. land economics) or by

proposing grand theoretical narratives (as in e.g. modernization). Hierarchical and heterarchic causal structures also avoid the haphazardness of context-specific explanations by imposing a standardized structural approach to causation that allows for comparisons. Specific causes may or may not apply across cases, and specific causal structures may or may not be similar, but we can determine that by approaching multiple cases with the same TFFD.

A third critique of the TFFD that comes specifically from social scientists is the "structural functionalist" accusation (cf. Bell 2005). Social scientists often view systems thought as embodying assumptions of structural-functionalism, which has long been criticized for dismissing questions of equity, justice, politics, and conflict. This is also reflected in political economy critiques and related perspectives in debates about modernization and development (Perz 2007, 2008). By contrast, much theorizing of LULCC has emphasized conflict and contestation, as in political ecology, particularly in developing regions like the Amazon (Schmink and Wood 1992). The impression sometimes given is that political ecology is incommensurate with approaches like hierarchy theory (Vayda and Walters 1999). We disagree, and draw on progressive contextualization, suggested by a critic of political ecology (Vayda 1985), as a means of incorporating politics and conflict into explanations for LULCC. We see affinities between the TFFD and political ecology, in that both feature cross-scale processes, which can include cross-scale politics and conflict. Moreover, a heterarchical causal structure also draws attention to bottom-up processes, which can include local mobilization to contest outside agents, as well as reorganization of causal structures, such as via contentious politics.

A fourth critique is the "abstraction problem," which we might also call the "implementation challenge." We have employed hierarchy, adaptive cycles, panarchy, and heterarchy as heuristics and applied them as theoretical tools, which opens questions about how they might be applied for empirical analysis. By extension, the resulting TFFD proposed here faces the same challenge. If we accept the theoretical advantages of the proposed framework, we must turn to the issue of how to apply it via methods and analysis. We offer four suggestions.

Meta-analysis is one way to evaluate theory. By reviewing many publications of empirical work for a range of study cases, we can appraise the scope of applicability of various theoretical explanations. Meta-analysis has become an important tool for evaluation of theory for the land science community (Geist and Lambin 2002; Rudel 2005). An extension beyond previous efforts would be to emphasize the scale dimension, in order to identify the scales on which prominent causes operate and how they interrelate. This would allow identification of different causal structures – hierarchical or heterarchic – that goes beyond the more basic distinction between proximate and underlying causes. However, meta-analysis begs questions about how a TFFD can inform, rather than just organize, empirical research.

One application is via dynamic simulation modeling (see examples in Gutman et al. 2004; Lambin and Geist 2006). The availability of spatially explicit data for socioeconomic and especially biophysical indicators, often derived from satellite images of land cover itself, allows construction of models that incorporate data

on various spatial scales. Further, ongoing monitoring efforts, including via satellite remote sensing, afford dynamic modeling with multi-temporal data, increasingly on multiple temporal scales. Such data sources have fed agent-based models which combine spatial data with decision rules to model landscape change (Parker et al. 2003; see examples in Gutman et al., 2004; Lambin and Geist 2006). The limitation of agent-based models however resides with their lack of recognition of causal agents beyond proximate agents who make land use decisions. Multi-agent-based models, which incorporate contagion effects, begin to account for larger-scale processes.

Another approach to modeling that places emphasis on larger-scale contextual effects is multi-level statistical modeling (e.g. Pan and Bilsborrow 2005; Vance and Iovanna 2006; Overmars and Verberg 2006). Most such models assume nested hierarchies in defining actor–context relationships, and most such models employ two or at most three levels. Even then, the data demands can be formidable, especially for social science data that are not pixel-based and not easily aggregated or disaggregated. Further, computational requirements can also be difficult, especially since maximum likelihood estimates may not converge, even for large data sets for the smaller-scale units, if the larger-scale aggregate units are not sufficiently numerous. Nonetheless, multi-level modeling packages have made strides in recent years beyond limiting assumptions of a few levels, and data and computational power allowing, they provide a means of directly testing scale-sensitive theoretical frameworks like the TFFD for empirical cases.

A final avenue is the employment of historical-comparative methods (e.g., Rudel, this volume). Whereas land change science has emphasized deductive methods and quantitative modeling, historical-comparative approaches combine deduction and induction as well as qualitative and quantitative methods. In addition, historical-comparative research in the social sciences seeks to balance generalizability and context-specificity (Tilly 1984; McMichael 1990, 1992), in the same spirit as the TFFD. The approach is to adopt an analytical focus on an outcome, such as LULCC, and then ask questions and collect data in order to derive an interpretation for each of several cases, whether for the same place over time or for multiple sites or both. In practice, this combines theory and method as the methods involve both theory-driven data collection as well as an openness to gathering additional information that is important to understanding specific cases. In this regard, progressive contextualization can be deployed as part of historical-comparative data collection to sort through causes on multiple scales. The important point with historical-comparative methods is that explanations can be fit into a TFFD by recognizing the scale-specificity of causal factors. Deductive and inductive approaches can be employed in series or simultaneously as the analyst identifies explanations for LULCC. Historical-comparative methods extend beyond published academic literature, and thus meta-analysis, by focusing on primary and secondary data sources.

Historical-comparative methods also stress the nature of the comparisons to be made. Analytical decisions must be made a priori to the analysis as to whether the comparisons will highlight uniqueness, commonalities, or situate a given case in a larger structural context (Tilly 1984; McMichael 1990, 1992). The land science

community has tended to gloss over some of these distinctions, emphasizing commonalities and uniqueness. Less attention has gone to other forms of comparison, one of which is to situate cases in broader contexts. This can be extended to situating scale-specific causes for a given case in larger scale contexts, as in progressive contextualization and hierarchical (and heterarchical) analytical frameworks. Particular attention to the scale of specific causes in each of several cases constitutes an elaboration of historical-comparative methods via application of the TFFD we have proposed, and would facilitate comparisons of the arrangement of explanations in causal structures for many different cases.

While the focus of a historical-comparative analysis must be decided at the outset, the cases to be selected, key explanatory factors chosen, and the scales of observation are managed provisionally. This then allows specification of the explanations (and the scales on which they operate) in a flexible fashion, not only to allow revisions as additional data are collected but also as causation of LULCC alters over time. Where the structure of LULCC causation is highly plastic, historical-comparative methods have an advantage in themselves being flexible in providing explanations provisionally, allowing for comparisons in causal structures over time.

There is no facile panacea for an ironclad theoretical approach to understand secondary growth and other LULCC, or to empirical applications. We have mentioned critiques of meta-analysis, dynamic simulation models, multi-level statistical models, and historical-comparative methods. We would add that some of the applications we have suggested are either new or have yet to be applied much to the case of LULCC; they remain to be fully tested. For now, we repeat that the TFFD overcomes limitations in other theoretical approaches to explanation of LULCC. While the TFFD harbors liabilities due to its inelegance, that is a reflection of the challenges facing integrative theoretical frameworks seeking more fully understand secondary growth and other LULCC, which alternatives heretofore address but inadequately.

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